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# Human Factors in Dairy Industry Process Control for Energy Reduction

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*Abstract—Reduction of CO<sub>2</sub> emissions is a challenge in all sectors and in particular the dairy processing industry.*

*Pasteurisation is an element of the process with relatively high energy consumption but is difficult to tackle due to a number of technical factors including lack of sub-metering. The plant is semi-automated and tasks subject to the discretion of the operators include: sequencing of process steps (known as “recipes”); scheduling of clean-in-place operations, and time spent circulating hot or cold water; responding to problems relating to operation and scheduling remedial action. This study uses semi-structured interview and ethnography at two UK dairy processing sites, to investigate the human factors affecting the operators who are involved in controlling a dairy process and to understand their current and potential role in reducing process energy consumption; there is particular reference to pasteurisation. The study finds communication of energy saving as a priority from management is important but on its own is not sufficient without useful information on energy consumption. The sites studied were from a company with a progressive energy policy at high level; however it was observed that energy efficiency was not perceived by the operators as a priority with regard to process control. Information on process energy use was not available to the operators in a form that would enable them to identify potential energy savings. The operators at the site can be seen to have a high level of skill in managing conflicting control priorities, interpreting process data and using their judgement to intervene and make improvements. This leads to the conclusion that provision of energy consumption data along with communication on the need to reduce energy could result in operators being able to make useful interventions in process operation that could result in energy reductions.*

**Keywords**—energy; process; dairy; pasteurisation; human factors; ethnography

Word count 14,510 including references

## 1. Introduction

This paper concerns the study of process control operator behaviour within the dairy processing industry. The paper investigates the operators’ current and potential role in reducing the energy consumption of the production process and what are the barriers and human factors that need to be taken into consideration to allow operators to control for energy reduction on an ongoing and dynamic basis?

Milk production globally contributes 2.7% of total global emissions, the majority of this figure relates to cradle to farm gate emissions. Methane contributes approximately 52% of the GHG emissions from milk production (FAO 2010) whereas approximately 8% of the total GHG emissions attributable to milk are generated post farm gate (FAO 2010).

Within a dairy processing site, pasteurisation is a common process element that accounts for 30 to 40% of the process energy use on site (CIPEC 2001; Modi & Prajapat 2014; Ramirez et al. 2006; Xu & Flapper 2009). The dairy industry has made progress in reducing energy use, between 2000 and 2010 the dairy processing sector made a 28% improvement in energy efficiency (The Dairy Roadmap 2013). For much of the industry, the focus has naturally been on the easier to tackle elements such as good housekeeping, boiler and refrigeration technologies etc. The efficiency of process operation remains a harder issue to tackle, particularly in areas of the process that are under-monitored (for energy) and also where there is a perceived conflict between the need to control the process for product quality and safety aims and the need to reduce the energy use of the process (Bunse et al. 2011; Hasanbeigi et al. 2010; Palm &

Thollander 2010; Thollander & Ottosson 2008; Rohdin & Thollander 2006). As highlighted by Blok (Blok et al. 2015) current production processes are far from ideal when it comes to sustainability. It can be said for many industries, including dairy processing – there is little visibility over key process energy use and energy as an issue has been deprioritised. In short the problem is that there are both human and technical barriers to controlling dairy processes for energy efficiency. Here our particular interest is in the way operators perceive their capability and responsibility to effect better energy efficiency, and what factors could enable the operators to do so in the future.

Operators control plant largely through SCADA (Supervisory Control and Data Acquisition) systems. Control algorithms are typically pre-programmed at site and/or process unit commissioning. All the system elements (valves, heat exchangers, flow monitors, tanks etc.) are assigned a unique “tag” (alpha-numeric label). The control algorithms contain routines for how a particular element of the process will run e.g.:

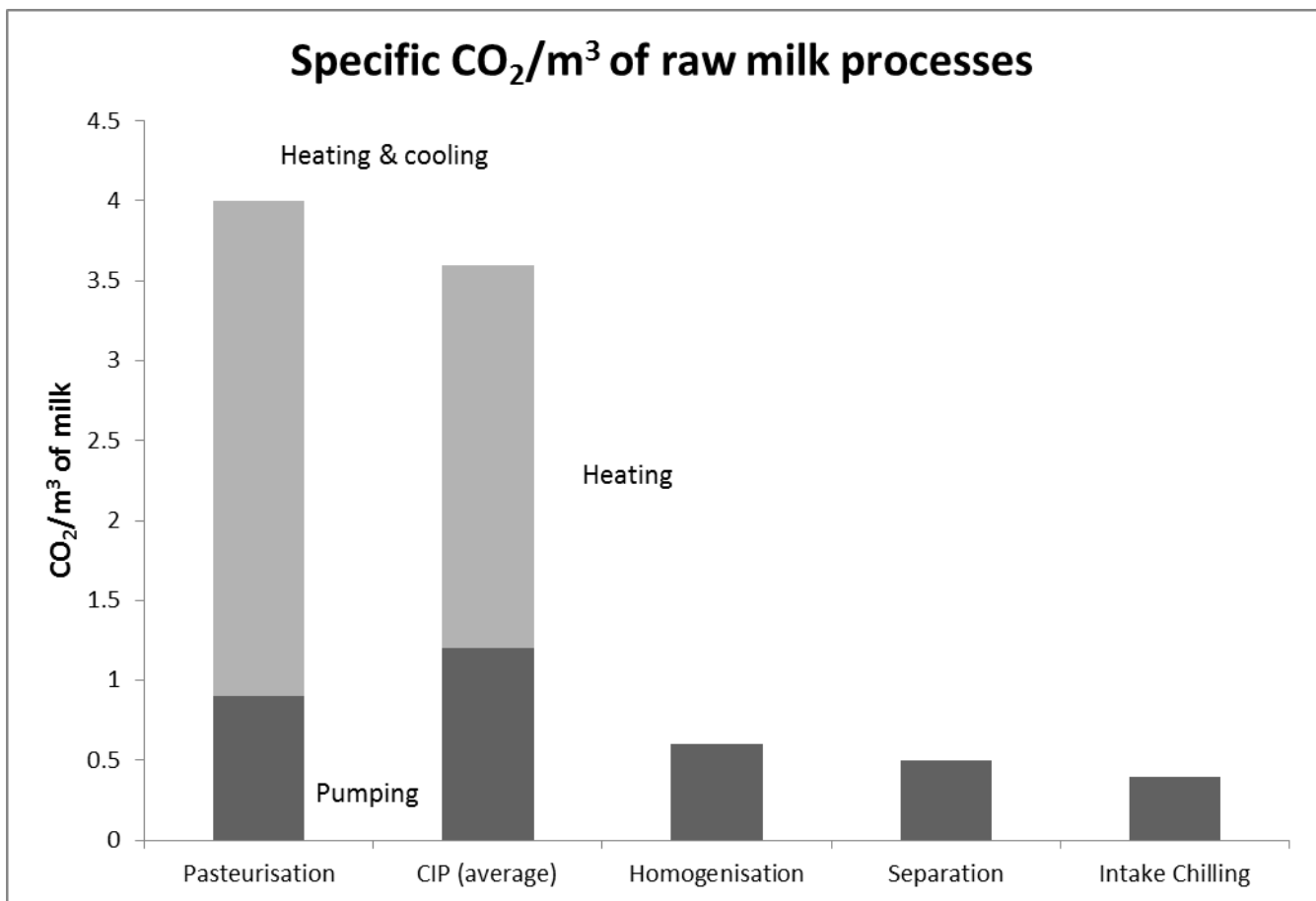
- Valve DP01V001 set to open
- Pump DP01P001 runs for 10 mins

Some elements have set temperatures to reach, sub-routines and control algorithms will work to ensure a steady temperature is maintained by varying the valve open % position on a hot or cold water feed. Feedback control will be used to maintain the temperature.

Much of this detail is programmed at commissioning and then left. The programming is done with the intention of optimising a key parameter of the process operation, this is typically related to quality control. For the majority of process plant, the control system is not set up to optimise energy consumption. The pasteurisation process is automated for product quality and sterilisation but not for energy saving.

Site staff plan and schedule routines in order to achieve the required product volumes. They also have the ability to halt programs and over-ride them for example adding in a cleaning operation or choosing whether to leave a process element in water circulation mode (water circulating where there would normally be dairy product and some process elements e.g. cooling, deactivated) or to run a clean in place (CIP) and leave the system to dry and cool.

Pasteurisation is the most common thermal process within the dairy processing industry (Ramirez et al. 2006); 87% of all milk consumed in the UK is pasteurised (Foster et al. 2007). Pasteurisation is the most energy intensive process in terms of energy, cost and carbon for liquid milk processing see figure 1 (The Carbon Trust n.d.). Diagram courtesy of the Carbon Trust Industrial Energy Efficiency Accelerator- Guide to the dairy sector. While the precise details are not clear for what is included within the data that make up this figure, it is likely that within the pumping energy for pasteurisation there is both product pumping and hot water circuit pumping included. In addition the study may have included pumping of secondary refrigerant. It is important to note that pasteurisation is a process with more inherent waste. As a thermal process there are typically periods of water recirculation (this will vary by site as to the average duration) where the plant is not pasteurising product, but hot water is being recirculated in order to keep the system to temperature. Homogenisation and separation are either in production or in cleaning mode, or off.



**Figure 1 Relative energy intensity of raw milk processes**

Verhulst and Boks (Verhulst & Boks 2014) highlighted success factors in achieving sustainable business transformation that fall into two main groups; those tied to structures, processes and technical issues and those linked to the internal value chain including human factors.

Energy management practice has been around as long as industry, though it emerged as a recognisable discipline in the 1980s. Energy management principles are well understood in business, however real life application can be constrained and stuck in an “accepted” way of doing things (Wesselink et al. 2015; Boons & Lüdeke-freund 2013). A systems approach using cross disciplinary techniques is helpful to understand how the production process really operates and what is needed to achieve the aim of improved process efficiency (Wesselink et al. 2015). Our study sites are from a parent company with a progressive energy policy however we find onsite and in our consulting experience that control priorities do not include energy.

The Carbon Trust Accelerator (Carbon Trust n.d.) identifies a wide range of energy intensity across the industry (Figure 2 reproduced by permission from the Carbon Trust). Some of the differences are accounted for by the inclusion of energy intensive processes such as evaporation and spray drying but variance is also explained by differences in application of good practice measures relating to energy.

For the purposes of energy saving, pasteurisation is often insufficiently monitored, such that the chilled water and steam inputs are not metered. Also too few temperatures across the heat exchangers are measured to allow heat transfer and efficiency of the units to be calculated (see figure 3). This makes pasteurisation something of a “black box”, where some inputs and outputs are known, but energy consumption is not. This means the task of identifying

inefficient operation and improvement opportunities relies on periodic reviews of data collected from temporary monitoring alongside data downloads from SCADA.

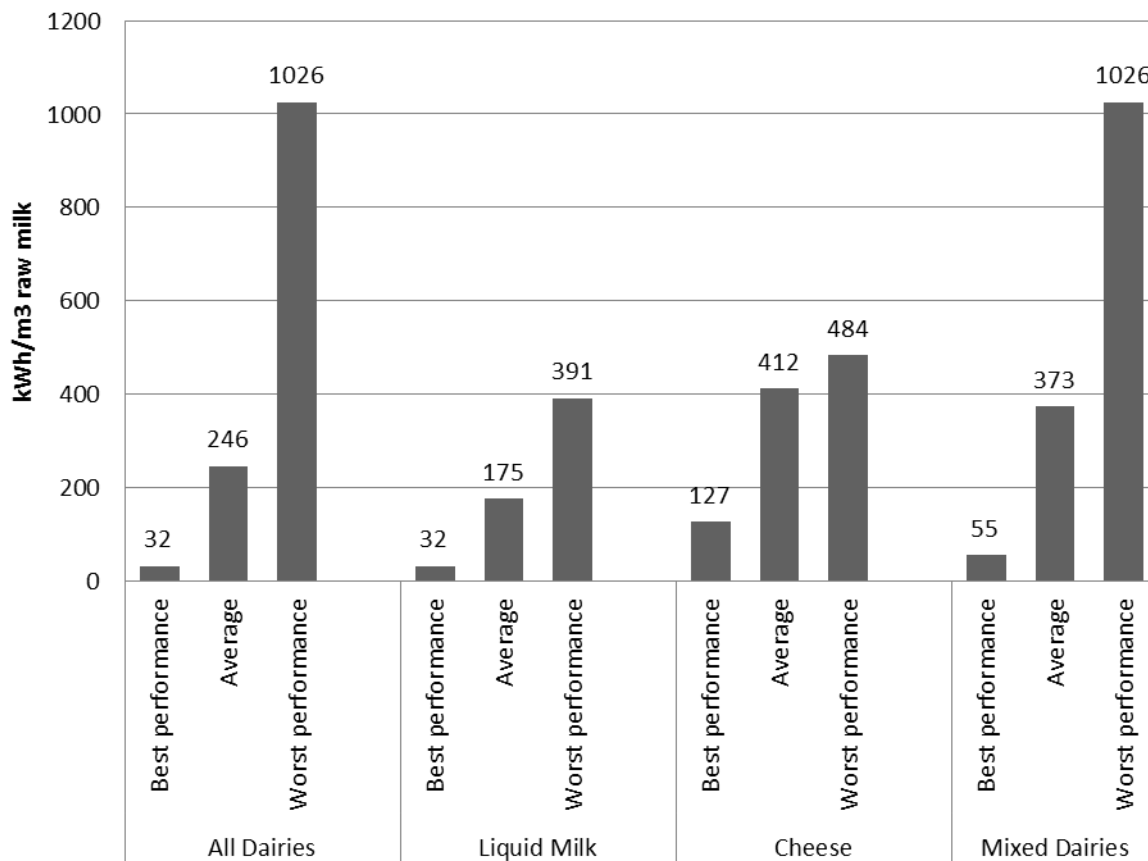


Figure 2 Range of energy performance across the main dairy types

A technical solution would be to provide process operators with improved, real time, information on energy consumption within the process, either through additional metering or analysis of system behaviour. For any technical solution to be effective, the human factors need to be considered relating to

- Would the information be used, and if so how?
- Why hasn't this been done already?
- What format of information would be most helpful?
- What are the issues regarding implementation and use?

Our research comprises semi-structured interviews, deliberately carried out in the workplace. We classify the approach as 'ethnography' in conformity with the ideas of Hammersley (Hammersley 2006). Use of ethnography to address energy efficiency in this setting is unique. Ethnography gives richer information than statistical methods; responses are not constrained or predetermined by the researcher's interview plan (Appendix A).

The benefit of ethnography is a rich description of 'daily life' eliciting the experience of interviewees; such experience would not readily become evident from formal interview methods or questionnaires. The aim of this study is to address those issues using a combination of semi-structured interview and ethnography in order to produce a case study, that asks "Why is controlling for energy efficiency within pasteurisation so difficult?"

## **2. Literature Review**

### **2.1 Why is controlling any process for energy efficiency difficult?**

Energy efficiency endeavours within an industrial setting have a long history and there exists much practitioner based literature in addition to academic papers. Within the practitioner sphere, the industrial energy efficiency challenge has traditionally been seen as something additional to process management and top level issues. There is a need to integrate energy management into process management, which are often treated as discrete elements with low status and low priority given to energy management (Bunse et al. 2011). In designing processes, optimising for energy use would come as lower priority. A process will be designed to achieve the required process quality with the lowest cost. Energy comes into those costs, but dependent on the industry – product wastage, time and labour may be more dominant features. Rising energy costs and costs resulting from legislation and regulation have pushed up the energy cost element in more recent years. Processing costs of milk (as distinct from overall production costs including farming) are not readily available. Within the overall costs of milk production across Europe, energy costs made up 18-22% of overall costs and 13% in the UK(2007 data)(States 2011).

A number of studies on the barriers to energy efficiency measures being implemented within industrial settings have been carried out. These studies have typically focused on management level decisions regarding the importance of energy and investment in energy efficiency. Risk to process comes out as a top or highly rated barrier (Thollander & Ottosson 2008; Rohdin & Thollander 2006; Palm & Thollander 2010). It has become part of organisational culture for top management to focus on the core business, i.e. the production process (Sandberg & Söderström 2003) and its outputs and sales. Such prioritisation is to the detriment of analysis of and investment in energy efficiency. Investment project ideas coming from an energy manager or estates person, rather than someone central to production, are not seen as strategic and may be viewed as lower priority (Sandberg & Söderström 2003). A Swedish study by De Groot, Verhoef, and Nijkamp (De Groot et al. 2001) has “other investments more important” and “energy efficiency has low priority” as the most significant barriers to investment. Tonn and Martin (Tonn & Martin 2000) highlight barriers mainly come down to lack of knowledge regarding benefits and opportunities or that this knowledge is too dispersed across the company.

Another Swedish study by Sandberg and Söderström (Sandberg & Söderström 2003) highlights how lack of sub-metering and proper measurement is a significant barrier to investment in energy efficiency. Energy Efficiency Watch Country Report for Sweden (Energy Efficiency Watch 2013) identifies Swedish energy efficiency policy as “comparatively ambitious”. Even so, within Sweden Rohdin and Thollander (ROHDIN & THOLLANDER 2006) highlighted how all but one of the non-energy intensive manufacturing sites they had spoken to had no sub-metering. (Industry accounts for 38% of energy consumption in Sweden (European Energy Network 2014)). As highlighted by Michaelis (Michaelis 2003); innovation is required to engage with the production process and push for greater energy savings in all areas not just those that are low risk and easy to tackle.

### **2.2 What control systems are used in dairy processing? Can they control for energy efficiency?**

The majority of dairy processing plants are controlled by a SCADA (Supervisory Control And Data Acquisition) system. Numerous commercial SCADA packages exist; they all work on similar principles. The system gathers data from across the process and controls elements (e.g. flows) in order to achieve relevant set points (e.g. temperatures).

Process control systems are designed to be flexible with regard to the metrics a site wishes to control for (Froisy 2006). However, within a standard package, it can be difficult to deal with conflicting control metrics of quality vs energy use. Single set points have to be chosen, usually based on product quality requirements. If energy sub-metering is absent, automatic control by SCADA for energy will be difficult.

The review undertaken by Herrmann, Thiede, Kara, and Hesselbach (Herrmann et al. 2011) of commercially available manufacturing simulation tools shows that they do not readily support the modelling of energy flows and rely on add-ons or separate data analysis tools. Software tools exist for decision making in production planning, but many of them do not include energy as a key factor in control decisions (Bunse et al. 2011).

Giacone and Mancò (Giacone & Mancò 2012) attempt to build models that can represent the energy flows across a complex industrial process. The energy system of a site is represented as single matrix equation, but has a number of

flaws as a real life model as it assumes energy use depends linearly on a single factor. Other attempts rely on creating and reviewing simulated scenarios for different control strategies (Herrmann et al. 2011; Herrmann & Thiede 2009).

Tomasula, Yee, McAloon, Nutter, and Bonnaillie (Tomasula et al. 2013) create a customisable model of the fluid milk process in order to understand the energy usage of the entire process. This model can be used as a benchmarking framework or to test potential process changes and the energy impact. On its own it would not reveal any real-time information about energy use of the plant.

### **2.3 Human factors as barriers to energy efficiency – what do we know already?**

Within this study we are aiming to understand the human factors in controlling a process for improved energy efficiency. Palm and Thollander (Palm & Thollander 2010) categorise barriers as economic, behavioural or organisational, this same structure is also used by Hasanbeigi (Hasanbeigi et al. 2010). The behavioural barriers identified by Palm and Thollander (Palm & Thollander 2010) are:

- Inability to process information
- Form of information
- Trust
- Inertia

Verhurst and Boks (Verhulst & Boks 2014) look at human factors relating to implementation of sustainable design practices, they find the key issues to be; resistance against change, internal communication, empowerment and organisational culture. Bauman 2002, Boks 2006 and Willander 2006 (Bauman 2002; Boks 2006; Willander 2006) call for a better understanding of these human factors.

(Turner & Karasek 1984) highlights that it is much easier to design for physical ergonomics than cognitive ergonomics given:

- Unpredictability of information, which decreases efficiency through a reduced ability to detect patterns, constant searching and concentration is required to detect unpredictable signals.
- Environmental factors, that cause distraction, and stress
- Degree of operator autonomy should be related to the skill of the task
- How heavy the workload is

There are issues with having too many control objectives to balance.

In order to prompt the operator to intervene in the process to improve energy efficiency, information has to be provided regarding the operation of the process. The form of data visualization for process control is vital. If done well, vast amounts of data can be comprehended rapidly (Ware, 2012). Good visualization facilitates pattern recognition and deviations from normal operation to stand out. Ware (Ware, 2012) provides guidelines for designing data visualisations including:

- Human sensory capabilities need to be taken into account so that important data points and patterns can be perceived quickly
- Unless the benefit is considerably greater, use tools that are consistent with others already in use.

A trend based system gives greater context to the energy information (Kivikunnas 1993). Just the simple act of being able to see if energy use is increasing (either gradually or from a step change) along with examples of traces of other corresponding process data – gives an operator sufficient information to investigate and intervene in a process.

### **2.4 Has anyone else used ethnography to understand the difficulties in process control for energy efficiency?**

Control room ethnography features in this study. Within the literature, control room ethnography centres around high risk and dynamic control scenarios such as blast furnace supervision (Hoc 1993) or military command centres

(Stanton et al. 2006). A dairy control room would typically be a lower peril environment but some interesting parallels can be drawn. For example if the knowledge required to best manage how a situation is dealt with is distributed amongst a number of parties. Or if the situation is complex with a variety of information sources; considering how the parties go about decision making.

Muir and Moray (Muir & Moray 1996) explore the issues of trust in automation. This uses the scenario of pasteurisation control (though this is incidental to the conclusions). The paper brings out useful points regarding the importance of getting the control model right if the results are to be trusted and the automation is not to be overridden.

Papers in the exact sphere of ethnography regarding industrial process control for energy efficiency have not come to light within this search. Much literature is available on ethnography to study control of buildings for energy efficiency. The key difference being that the control of building environments (and the subsequent impact on energy use) is typically by occupants with vastly removed priorities and tasks. The control of the building environment is incidental to why they are in the building, and for most people; their attitude to energy and the environment do not factor in their day to day decision making (Crosbie & Baker 2010; Lutzenhiser 1993). Control of a workplace building for energy efficiency (if left to occupants) may be through guidelines as opposed to formalized work processes (Schwartz et al. 2010). Schwartz, Bell, Ramirez et al (Schwartz et al. 2010) do demonstrate however that workers do take responsibility for energy reduction if given the necessary support. Control room operators are tasked with controlling the process even if they have not been tasked with controlling a process for energy efficiency.

In addressing the challenge of process energy efficiency, the human element, including barriers and opportunities, must be understood. Ethnography offers a deeper insight into human behaviour than broad brush surveys and statistical data and it is surprising to find its use absent to date.

To refer back to the four questions set in the introduction;

- Would the information be used, and if so how?
- Why hasn't this been done already?
- What format of information would be most helpful?
- What are the issues regarding implementation and use?

As identified in the literature review, there is very little literature focusing on the operator role in reducing energy consumption in industrial processes. The literature review shows that some software and methods are available with a specific energy focus, however they do not tend to be in a form that is useful for dynamic real time analysis by operators. Section 2.3 has set out some information relating to visualisation and format and a great deal of literature exists on cognitive ergonomics, trends provide a great deal of information efficiently. Controlling a process for energy is difficult because commercial control software focuses on single metrics typically quality related and energy still isn't a management priority in many sectors and organisations.

## **3. Method**

### **3.1 Techniques Employed**

This study uses semi-structured interviews and ethnography to understand the human and technical issues and barriers to controlling pasteurisation for energy efficiency.

The value of ethnography is in identifying underlying causes and understanding the problem, that a statistical review of data would struggle to be able to do (Granot et al. 2012). Generalisations about a situation can be drawn from ethnography (Edwards 2015). Ethnography provides examples to help others visualise and understand the detail of a situation, but ethnographers should also seek out data to back up key issues (Edwards 2015). Workplace ethnography tends to rely on the single case study (Edwards 2015), which is the case with this paper.



Ethnography is a form of qualitative research involving observation of a place or people in order to provide an in-depth and rich description of “daily life”. Ethnography can help identify underlying factors and understanding of a problem or situation.

Interviewing practice has a variety of forms from very structured formats that constrain the answer set, to open interview methods that follow the course of discussion in a conversational manner (Granot et al. 2012). The semi structured interview format aims to find a compromise between a spontaneous conversational style and a ridged structured interview where much of the background detail is already established and answers to very specific questions are wanted (Leech 2002). The interview should be prepared for with a series of open questions that act as “jumping off” points for discussion. Grand tour questions are recommended such that they ask for the interviewee to give a much more descriptive and wide ranging response e.g. “Can you describe what happens on a typical shift?” (Leech 2002).

Access was provided to two dairy processing sites (sites A and B). An interview was held with ten staff members across the sites who have experience of process control. The interviews lasted for approximately half an hour, with participants questioned about the control process and energy consumption relating to pasteurisation. The interview was designed to be “semi-structured” with open questions, such that a discussion could develop, led by the answers of the interviewee. The interviews were all conducted at the control desks, while the operators were on shift. The style of the interview was informal and at times was led by discussion of the actions the operators were currently undertaking, it also allowed demonstration of issues and actions relating to the questions posed. Two further staff members engaged in in-depth discussions around similar topics, the outcomes of these are included in the results despite not being conducted in quite the same manner. Appendix B comments on control systems and the boundaries between human and machine control.

The aim of the interview was to understand operators’ perceptions of:

- The task of controlling the process
- The balance between automation and operator input
- The priorities operators have in mind when controlling the process
- Current energy efficiency monitoring processes related to pasteurisation
- What equipment is present (and functioning)
- What monitoring is used and how
- What could be improved

The interview was recorded on two digital devices and the interviewer also took notes during the interview. All participants signed a consent form. A flow chart of the starting question structure is shown in appendix A. The grey highlighted questions are the primary ones, with some potential follow up questions based on the anticipated directions the interview could take. The questions are primarily phenomenological in standpoint and are intended to help understand the interviewees experience and point of view. Some questions are positivist and look to establish facts e.g. “what do you monitor relating to energy”, but these are typically stepping-stones to phenomenological questions.

The interview was structured assuming that the following issues were central to the question of whether the process is controlled for energy efficiency:

- Lack of data on energy consumption
- Poor visualisation of energy data
- Low level of autonomy of the operator
- Conflicting control priorities
- Energy not communicated as a priority

The interview plan in appendix A was constructed before interviews. Note that (1) some questions did not result in productive answers and are not discussed in this paper (2) the methodology was flexible so that questions posed in-situ could divert from the plan (3) for clarity of presentation, the responses in section 4 have been restructured, and do not necessarily map onto the original plan.

The interviews were saved to the online software dedoose™, where they could be reviewed and coded. Dedoose™ is an online tool that supports categorisation, review and analysis of qualitative and mixed methods research materials such as text, audio files, videos and pictures. The answers and discussion have been summarised within the “interview results” section of this paper (section 4).

Time was mainly spent within the control room during the visit, some of the time was spent undertaking interviews but more than two thirds of the time was available for observation. Therefore, in addition to the semi-structured interviews; ethnographic techniques were used to capture details of operations and to understand

- Impact of semi-structured interview and observation on outcomes
- Culture of the control room
- Attitude to energy efficiency
- Issues with managing conflicting priorities
- Amount of control/autonomy of the system that operator has

and to collect general observations on the control room task – what do operators do and how?

We use the word ethnography as defined by Suryani (Suryani 2008) and Hammersley (Hammersley 2006) “...a form of social and educational research that emphasises the importance of studying *at first-hand* what people say and do in a particular context” (Hammersley 2006).

The ethnographic element comprised (in addition to interviewing) careful observation of all the control room activities (it being a limited space). Notes were taken by the author and conversations were recorded on a digital device. The author also asked questions of the control room occupants where appropriate.

The information from the ethnographic element has been used to create the case study in appendix A. The case study provides context for the observations in section 4 and the discussion in section 5. The intention with the case study is to give the reader a feel for, and understanding of what the role of process control entails.

The semi-structured interview and ethnography techniques were chosen because the authors required an in depth understanding on a narrow topic with the aim of ensuring that any technical solution to present information on energy use in pasteurisation will be of practical use. Ethnography provides insights into the real world situation, including potential unanticipated issues and behaviours. This method was preferred over statistical data gathering where an initial structure and questions have to be defined before a full understanding of the problem has been gained.

### **3.2. Review of the methodology**

The main shortcoming of this study is that it was limited to two sites due in part to time consuming issues frequently inherent in negotiating access to sites. It is therefore not possible to be certain whether the lack of emphasis on energy consumption is due to site culture and history or if it is more prevalent through the dairy industry and similar sites. The sites were of a significant size, the dairy processing industry is dominated by several larger operators. It would make the results more robust to visit other sites and carry out similar interviews and observations.

Only ten operators were interviewed, within this group the operators were of varying rank and from different sites and shifts, they were all however working in the operator role i.e. directly responsible for controlling the process. This is a relatively small number; however they were surprisingly homogenous in their responses, indicating that increasing the number of operators interviewed at the sites would yield similar results (Yearworth 2015). This in turn would necessitate a differently designed survey. There would, for example, be benefit in discussing with managers the energy saving philosophy at the sites. All interviews were conducted in the control room with other staff

members nearby. There is a possibility that an unwanted transfer of ideas between operators influenced their responses; however given the candid nature of the responses, this seems unlikely.

The semi-structured interview guide (appendix A) worked well and could be applied to other process industries (with minor modifications).

In order to add greater rigour to the ethnographic element it would be preferable to spend more time at the sites as an assumption made in this paper is that what was observed is reflective of “what always happens”; Hammersley (Hammersley 2006) point out that can be a shortcoming of modern ethnography.

#### **4. Interview Results**

The interview recordings and notes taken were entered into the online software “dedoose™”. The data was coded using four categories:

- Balance of Judgement – material that evidences the balance between automatic routines and manual input. (How much autonomy do controllers have?)
- Control priorities (what are the key issues that the controllers are dealing with, what are they trying to maximise, minimise or optimise?)
- Energy – any discussion relating to energy and how energy is being considered in day to day operations
- Visualisation – how is the data and information from the system being presented to the operators? How are the operators interpreting it and working with it?

Some material collected covered several of these categories. Quotes in italics are from the operators, and are transcribed verbatim.

##### **4.1 Balance of Judgement**

Operators respond to schedules detailing the production volume required for different products. They were observed to be responsible for (1) the selection of pre-programmed recipes, and linking these recipes in a series to obtain the required product (2) planning the timing of operations, so that (for example) production would align with packaging operations (3) sampling and checking products (4) necessary (minor) process adjustment (5) scheduling necessary cleaning and/or repair to plant (liaising with repair technicians). At issue were the perceived requirement for manual intervention, the role of operators in planning processes, the way in which operators dealt with incidents, and the implications for energy saving.

To keep structure in our paper but nonetheless retain the integrity of information, our interpretation of operator responses to questions is presented in the bulk of this section whereas

Table 1 comprises selections of relevant verbatim statements. (Appendix A lists the interview plan.)

With regard to manual intervention, some operators estimated that 70% to 80% of decisions were automated whereas others simply acknowledged the necessity of manual intervention (Q 1,

Table 1). Timing and planning required skills in working back from key events (e.g. a scheduled packaging operation) and considering the volumes of product available and when these volumes would become available, the availability of storage vessels, and the duration of processes (Q 2,

Table 1). The operators recognised their own capability to deal flexibly with minor emergencies.

Most of the judgements made were based on experience, developed alongside advice and guidelines from peers and managers. (

Table 1, Q3). Operators were observed to collaborate positively, cross checking each other’s work. They made minor adjustments to the process according to their experience. In terms of energy, operators felt that the options for using their judgement were limited. Judgement was more focused on the process variables getting to an efficient point i.e. running with the optimum through flow. (

Table 1, Q4)

Some of the complexity in decision making is illustrated by an event that occurred during an interview. The operator was interrupted by a technician following the rupture of a filler<sup>1</sup> during a Clean In Place (CIP) operation, leaking hot caustic soda (the cleaning agent). The technician requested that the CIP was stopped, but after cross checking a few aspects, the operator suggested that it would be preferable to wait about three to five minutes for the CIP process to enter a cold water cooling phase; this option was chosen following discussion. Consequently the plant was cooled to a safe temperature without the risk of caustic solution inside (the plant), mitigating risks to the technicians and allowing faster inspection and repair. Moreover the filler would only require only sanitisation rather than complete re-CIP once the technicians had finished<sup>2</sup>, saving time and cost of chemical, and mitigating environmental impact. The operator highlighted that the time saving from being able to sanitise rather than CIP was certainly a consideration. The episode required calm interpretation of an urgent request, communication between the parties to understand the facts and decide on the best way forward. The operator sought to balance a number of priorities including both immediate and upcoming safety concerns, time and chemical use reduction.

Table 1 Operator Perception of Judgement

Question number	Question or prompt	Selected Responses
1	"Can you describe the balance between human judgement and automatic sequences and routines?"	<p><i>"pasteurisers are 80% automatic"</i></p> <p><i>"70% automated, 30% operator"</i></p> <p><i>"you could just set the system up and leave it running in theory – but it needs manual intervention".</i></p>
2	Discussion following on from question about process of controlling plant (Q1 above).	<p><i>"I'm always thinking one step ahead" "might lose your plant halfway through the run due to exceptional circumstance like a valve or a failure, pasteurization failure or homogenization failure or breaking a belt, anything can happen ...just got to keep looking at the tanks and work out what tanks are going to come back next."</i></p> <p><i>"We come in on a morning and we know what we have to do everyday...we'll be looking how things are going, and that'll dictate, depending on what's running and what products we've got available to us at that time, dictates what we can do next. So although we come in and have a plan to do A,B&amp;C we might end up having to do B,C&amp;A. Things change, but we're quite flexible to do that"</i></p>

<sup>1</sup> Section of the production plant for filling product containers, for example with liquid milk.

<sup>2</sup> CIP is designed to remove build-up of product residues and is a more intense process that typically ends with a sanitisation phase. Sanitisation alone can be performed where the only concern is removal of micro-organisms. (SPX 2013; Thomas & Sathian 2014)

3	Discussion regarding training	<i>"It's basic training on the job...by running the plant...common sense"</i>
4	"How does energy consumption of the plant come into day to day operations?"	<i>We have to use that energy, the energy that the evaporator uses I haven't really got any control over, I can't slow it down, I can't reduce the temperature of it, it is what it is, so I can concentrate on getting what we got coming out of the other end right". "We can't change any set points on the plant whatsoever...I can change the fats, silos where I put my cream, cream set points, that's all, I can't change any temperatures..."</i>

## 4.2 Control Priorities

Operators were responsible for controlling the quality of product, through correct set point temperatures at the required holding time, and achieving specified product volumes. Environmental, health and safety stipulations formed a background to these activities and forced constraints on operation (Dairy UK 2010).

Table 2 summarises verbatim quotes from operators. Depending on location of plant, perceived priorities included mitigation of product loss or availability of water (Q 1) – this was apparent both from interviews and discussions within the team. Energy saving was not seen as a priority (Q 2). Operators were not monitoring the plant for evidence of fouling (Q 3) and one can reasonably assume that, by default, they treated the recommended times between clean-in-place operations as optimum. The plant was more likely to be stopped owing to pre-determined limits on run time, or when a storage tank was filled (and the inevitable part filling of a second tank before the end of a shift was deemed unacceptable).

Achieving volumes at a consistent pace is something that the operators mixing cream at site B highlighted as having an effect on energy consumption (fewer CIP operations would be necessary)(Q4). The operators planned to avoid excessing plant stoppages and the ensuing cleaning operations. They could only leave the plant in standby for 6 hours before cleaning was necessary; provided that it is running a plant can operate for 24 hours between cleaning operations.

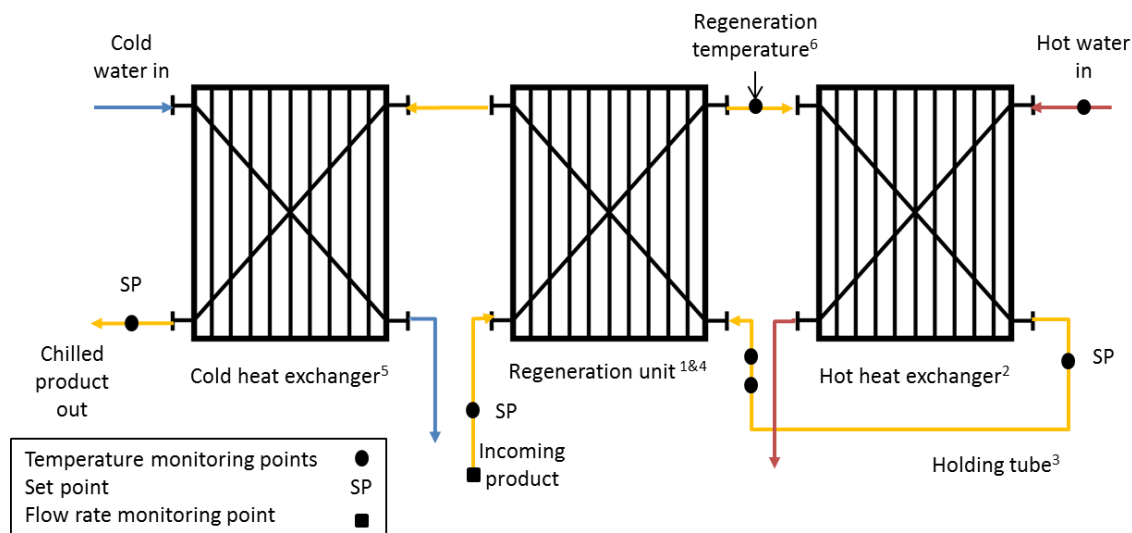
Site A had historical issues with water supply volume, the need to reduce water consumption had been communicated and it was clear that the operators included water reduction in their list of control priorities (Q5, Table 2).

The operators managed conflicting priorities and there was a perceived hierarchy of priorities as communicated by management; this currently, for site A, excludes energy saving.

**Table 2 Operator Perception of Control Priorities**

Question number	Question or prompt	Selected Responses
1	"What are your objectives in monitoring the system?" and discussion around control priorities	<i>"Where are we loosing cream? Are we loosing cream? Does get questioned a lot, important not to be blasé and think you've fixed it, especially losses. Losses is massive here" "there's much more emphasis on it [cost] now".</i>  <i>"cost is huge" ["huge" implies "very important"]</i>
2	"Do you look at energy in anyway?"	<i>"No. No...there's other people who look at that, we don't". "I've never really been taught to monitor the energy".</i>

		<p><i>"You could look at that tag [temperature of product after regeneration; "regeneration temperature" see figure 3] the whole day and not even think about it, whereas these three [holding tube temperatures see figure 3] are critical to us in running the pasteuriser".</i></p> <p><i>"the main thing we can do something about is [product] losses, that's what they try and make us focus on"</i></p> <p><i>"no matter how much energy we use we need to pasteurise something".</i></p> <p><i>"Would still run the process the same if it used half or twice as much energy".</i></p>
3	Discussion relating to whether suspected fouling ever leads to a CIP	<i>"We rarely come off [stop the pasteurisation process] early because it's fouled, we normally come off because we've hit our 16hrs".</i>
4	Discussion regarding actions operators can take that lead to reduced energy consumption	<i>"[they plan to run at a] consistent pace because if you stop at any time you've got to clean again...we're forever saying 'we don't really want to clean again'</i>
5	"what are your priorities for control?"	<i>"water...I got electric, I got gas, I got oil, I know that. Water...we use a massive amount of water in our processes...recently this year actually we increased the amount of water coming into the factory...we didn't used to have the supply. We've addressed that problem... We're constantly monitoring our water levels our water supply and I'm constantly in conversation with our butter leader "what are you washing?" "what do you need to wash?"...it's something you need to react to as you go through the day"</i>



The point of the regenerator is to capture and re-use as much of the heat that has to be removed from the product after pasteurisation temperature is reached. Regeneration efficiencies of up to 95% are possible (TetraPak 2017) from a well maintained and run unit. The regenerator is a hugely important tool in improving pasteurisation energy efficiency.

1. Raw (cold) product enters the pasteuriser into the regeneration unit. The raw product is preheated by pasteurised product leaving the system
2. A heat exchanger brings the product up to the temperature required to achieve pasteurisation
3. The heated product passes through a holding tube for the required amount of time to achieve pasteurisation
4. The pasteurised product is cooled by exchanging it's heat with the incoming product
5. The pasteurised product is further cooled to the required storage temperature
6. The regeneration temperature is not often monitored. It is the temperature of the product after it has been heated by the regeneration stage. It can be used to calculate the heat transfer across the system and regenerator efficiency.

**Figure 3 Basic pasteuriser model**

### 4.3 Energy

At site A, Operators did not consider energy savings although there was a feeling that (unspecified) staff in the organisation should take responsibility (Table 2, Q 2). At site B, on the other hand, energy use was discussed at daily meetings (Table 3, Q 2).

One operator clearly identified the importance of the energy consumption of the evaporators and the dryers. The evaporator (at site A) was instrumented to show mass flow (in kg/hr) of steam used but the sensor was inoperative. The operator felt that knowing energy use would have minimal impact on his actions and choices (see also Table 2, Q 2 and Table 3, Q 5).

The operators are responsible for interpreting a large set of readings and alerts. An operator at site A described various ways by which they could infer the impact of fouling from increased pump power (applied by SCADA control to keep the mass flow rate at its set point) and increased back pressure (Table 3, Q 3). It was felt that available direct information on either energy use or the impact of fouling would be used and exploited, provided this led to useful interventions in the process (Q 4). An advantage of site A was that it had two pasteurisation units with each having different levels of energy monitoring. It was clear therefor from the responses that even when the data is present, that it is not being used.

Primarily due to the SCADA routines comprising set "recipes" that the operator could select but not edit, most operators at site A expressed a concern that they could not affect the energy use of the process (Q 5). However, one operator identified profitable adjustments to the sequencing of recipes. For example, delaying a CIP briefly would

enable the pasteuriser to attain its operating temperature, ready to operate immediately on completion of the CIP. The requirement for hot water circulation through the pasteuriser would thus be obviated.

At site B, it was clear that some ideas regarding ways to improve energy efficiency had been communicated, including the message to minimize time on water recirculation (Table 3, Q 6).

The operators demonstrably understood the importance of energy saving. For example, at site B one operator (when asked about energy reduction) led an impromptu tour to see the location of sugar which was conveyed by compressed air blowers across 2 rooms to the mixers. The operator pointed out that this location seemed unnecessarily remote. While this is a capital fix, not operational, the clear understanding of how energy can be reduced is demonstrated.

**Table 3 Operator Perceptions of Energy Saving**

Question number	Question or prompt	Selected responses
1	Discussion following on from question "What do you monitor relating to energy?"	<p><i>"I can understand the need for the temperature on the outlet and the inlet... [regeneration temperature] what's the use of it?"</i></p> <p><i>"It's probably monitored but not where we can see it".</i></p> <p><i>"This [energy use data] isn't something we monitor, it's there...it's giving you a reading there, but how effective is that..."</i></p> <p><i>"I've never really been taught to monitor the energy side of it, I'm not sure if anyone else does neither...if we had the correct kit to monitor it, I think it would be quite easy"</i></p>
2	"Is energy mentioned in meetings?"	<p><i>"[there] probably is a lot of meetings about energy but I wouldn't know"</i></p> <p><i>"the only time energy would come up is if someone brought it up as a continuous improvement idea"</i></p> <p><i>"gets mentioned every morning at review meeting, not sure but I think it gets escalated at other meetings."</i></p>
3	Operator comments on fouling	<p><i>"flow rate here, feed pump running here... if flow rate is set and pump is running at a fixed %, you can tell without the energy meter on there... how hard your pump is running... the harder your pump is running you can normally tell how fouled your pasteuriser is...we don't really monitor that, to be fair".</i></p>
4	Operator interest in energy monitoring	<p><i>"try to reduce wastage anyway, but if I knew what certain machines or areas were consuming then I think I'd take more time to minimize energy consumption. I'm maybe not going to let this run for this long or I'm going to turn the lights off when I leave, things like that, if I knew that information, I'd just be a little bit more mindful"</i></p> <p><i>"I'd love to be able to see [what energy is being used]...that motor...it's running but it doesn't actually tell you what it's doing...it says 10% but 10% of what?"</i></p>
5	"Can you tell me about the balance between controlling for quality and energy consumption"	<p><i>"I've got to do my job...I can't even think of a way I could cut energy usage"</i></p>



		<p><i>“when I put a CIP on, I don’t think about anything, because the controls are in place to minimize wastage and minimize energy use, I don’t have any input on that, only input I have is if I have to stop one and restart it”</i></p> <p><i>“Energy is something we subconsciously consider...no one is saying to me you cannot use this many kW of energy...though excessive use would be questioned”.</i></p>
6	Operator strategies to reduce energy	<p><i>“we try and minimize the runs we do, we try and sterilize the plant as late as possible before we start the run” (to minimize water recirculation time)</i></p> <p><i>“try to keep going so you don’t have that stopping thing where you have to start motors again...”</i></p> <p><i>“try to minimize the number of times we stop &amp; start pasteurization runs”</i></p>

#### 4.4 Visualisation

This section of the paper considers firstly the availability of data and secondly its presentation.

At site A the regeneration temperature was presented to operators, but the corresponding heat input had not been computed and presented (equivalent to the product of mass flow rate, a specific heat capacity and temperature change across the regenerator – see Figure 3). The operators were unable to deduce the relationship between heat input and regenerator temperature (see Q 1, Table 3). The regenerator temperature is omitted from displays on many plants (including at site B).

At site B, a screen intended to provide energy data for a range of points across the process had never been commissioned. However the operators did question whether the single point readouts of kWh totals for chillers and corridor lighting would actually provide interpretable and useful data.

Site A used Aspen™ software with a trend function to view data. All operators interviewed independently pointed out the benefits of the Aspen™ trending screen, which can be customised to show traces of temperatures, pressures and flow rates from across the plant. In the event of a plant failure, operators could review the historic data so as to diagnose faults. The visualisation was thought to make diagnosis easier (Table 4, Q 1). It was felt that easy user customisation was slightly disadvantageous as successive shifts adapted different ways of working.

The available trending options at Site B were limited to checking the divert tests<sup>3</sup>. Asked what screens the operators used to monitor progress, each operator pointed out different screens, none seemingly optimal. One talked about how the act of recording key values on a paper log book helped to spot issues. Another talked about how the plant layout representations worked the best as all the tags could be seen at once and compared (Table 4, Q2). But two others found these types of screens too cluttered, with too many intersecting lines and little description of plant items and tags. It does appear that at site B, the operators are working as well as possible with less than perfect information. (Table 4, Q 2).

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<sup>3</sup> A test performed at the start of each pasteurisation run to check that the divert valve will operate successfully if the temperature of pasteurisation drops below the base set-point.

Table 4 Operator views on data visualisation

Question number	Question	Response
1	Trend visualisation comments from site A	<p><i>"What you'll get from this is an early indication if something is going wrong", "it's a really good indicator of what's happening", "I think it's brilliant myself, you can gauge exactly what's going on just looking at this one screen here", "it's probably one of the most handy bits of kit we've got on site...it could be used slightly better though"</i></p> <p><i>"Each different shift has their own different trends", "some people look at everything...it has basically no bearing on what you are doing in production whatever"</i></p>
2	Trend visualisation comments from site B	<p><i>"With these checks [noting pressures, temps etc.] I've just been through there you'd see it if something has risen sharply...after you've been doing it awhile you do get a sort of mental picture of where things should be"</i></p> <p><i>"It is quite busy...it takes a long time to come to terms with what's happening...I'll constantly throughout the run, click on that screen...I always look at the valve position... say it was always at 50/55% and I saw it go up to 60% I know that loop's starting to block up so I know I need to do something about it..." "you can cancel stuff out if everything is together"</i></p> <p><i>"It's like anything really...you get used to what you have...I think the set-up is quite good really".</i></p>

## 5. Discussion

The subtitles in this section refer to questions posed in the introduction.

### 5.1 Would the information (on energy use of the process) be used?

Energy performance information is not readily available to the operators for the pasteurisation units. However, at site A energy consumption information is available for another high consumption part of the process, namely evaporators. Operators understood clearly that evaporators were the highest energy consumers. This information on energy consumption is not used by the operators primarily because energy consumption in general is not emphasised as a priority and also the operators are not able to use the consumption information to formulate useful actions. The energy consumption of a piece of equipment is seen as fixed, i.e. a fixed load indicated in kilowatts. However the operators are aware that the consumption can be influenced through achieving optimum running efficiency, limiting standby, unnecessary running and idle baseload.

One concludes that, without communication on the need to reduce energy, information regarding the energy consumption of pasteurisation would not be used. However, the operators have a great ability to handle multiple priorities, take in many different factors and use experience to make judgements about process adjustments that result in product savings. Providing energy consumption information along alongside examples of how to interpret and use it (and encouragement from management) would likely be used.

The example from site A of how communication on the importance of water efficiency had led to operators including water in their list of control priorities (Table 2, Q5) demonstrates how it is possible for the same to apply to energy use.

### **5.2 How would the information be used?**

Energy consumption information would primarily be used to prompt operators to look at the process and see if they can intervene in any way to improve efficiency or identify changes to how they plan the day's work. Information may be used elsewhere in the organisation to monitor energy performance in a retrospective manner, but the greater need is about prompting immediate and dynamic action, such as spotting:

- when the cold utility is running unnecessarily when in water circulation mode
- when the pasteurization temperature is running at the top of the allowable range and could be reduced
- Excessive time in water recirculation mode
- the efficiency of the regenerator reducing due to fouling

The case study highlights that once the pasteurisation unit is up and running it is only checked periodically. Key readings are noted every hour but otherwise the operators do not have a habit of checking the running, mainly due to the lack of visualised information that would highlight any issue that wouldn't otherwise trigger an alarm. Site A does have the underlying data (regeneration temperature) and the trending system that would enable a trend to be set up that would allow operators to spot the kind of issues highlighted above. It would be a change in practice to monitor pasteurisation more closely during a run, however it would fit with practice relating to other equipment e.g. separators.

### **5.3 Why hasn't this been done already?**

As discussed in the introduction; energy consumption is being tackled enthusiastically through much of the dairy industry and elsewhere in the company. From the interviews and ethnography it is apparent that some of the operators are not told that energy consumption is important. Individual knowledge of the importance of energy consumption is good. Although operators are not hostile to the concept of energy efficiency, they simply do not discuss it regularly. Certainly the energy consumption information currently available is not complete, coherent or presented in a useful format.

At site B; operators are more aware of the importance of energy reduction, though they are not asked explicitly to control the process for energy. However, at the site, the energy consumption data on the process and necessary visualisation tools are not present.

As discussed in the literature review, it can often be the case that well intentioned energy management programs do not fully link up across an organisation or take a systems approach to look in detail at where input is needed. Verhulst and Boks (Verhulst & Boks 2014) investigate how can sustainability in generic product design be improved. The study takes place in organisations in Belgian and Dutch firms with an internal product development process and department, these are not food and drink processing firms, however the point of the study is in highlighting how energy management initiatives can suffer from lack of "joined up" implementation. Verhulst and Boks find for sustainability improvements to be brought about, it is not just by tools and improved processes but also by management engaging with designers— an approach which their study finds has been largely ignored. Verhulst and Boks identify the importance of training, followed by support from external and internal experts and sustainability champions<sup>4</sup>.

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<sup>4</sup> A sustainability champion role would typically be someone within the organisation who already had a passion for sustainability and can help convince others of the importance of sustainability from within the different levels of the organisation.

On any processing site, the energy efficiency efforts can encompass investment, policy, behaviour and core and/or non-core plant. Investment on core plant may be seen as posing less risk to the process than changes to behaviour and operation. That the site should have correctly sized, efficient equipment is self-evident. This paper explores the human factors contributing to energy efficient operation. A key point is that due to the high level of automation, lack of communication and lack of communication, energy efficiency is often not included in control decisions. Investment can be made on the plant, but the same operational challenges will remain. Operators are at the front line in terms of being able to identify and take action to tackle inefficient running. However, operators will often make decision based on a set of required outcomes without the visibility of the impact these actions are having on efficiency.

To answer this question fully for these sites would require interviews with management in addition to operators. More generally the answers may well revert to issues uncovered in the literature review. Previous literature on barriers to industrial process energy efficiency is concentrated at this manager level and so this has not been a focus here. Energy management culture as set by management is vital and the company engaged in this study has a very positive attitude, hence the willingness to participate. The focus of this study is on what is happening at control room level.

The interviews and ethnography uncovered no obvious barriers to presenting real time information on energy consumption over and above it requiring additional metering in some situations. The lack of metering is not an inconsequential point; however it is a well-covered issue in the field of energy efficiency and not a focus for investigation in this paper. It is also worth noting that many actions that improve the efficiency of the process, such as spotting high pasteurisation temperatures or when the cold utility is running unnecessarily in water circulation mode can be identified from existing monitoring data.

#### **5.4 What form of information would be most helpful?**

For site A using the Aspen™ trending software, the interviewees independently highlighted the software as being most useful in helping them gain an understanding of what was happening in the process. The operators use the software to set up trend screens for any element of the process. They can add on as many or few traces as they wish. In interpreting, the level, slope, disruption, interaction of, and changes to the different trends, they are able to see what has happened recently in the process, if it is still operating smoothly, and anticipate issues that may arise. They can then make manual interventions to the process to keep it on track.

As discussed in the literature review (section 2.3) trend views do give an operator a sense of how a process is changing over time and so they can pick out deviations from normal and also identify potential causes. In addition to trends, examples of useful interventions and any subsequent impacts the intervention might have would be very useful.

#### **5.5 What are the issues regarding implementation and use?**

For the site already using Aspen™ trending functionality, implementation of visualisation options would be straightforward as the existing software would allow a custom trace to be created relating to pasteurisation and energy.

The implementation issues arising are more likely to be around creating the supporting narrative of why it might be useful to save energy. Also providing a shortcut to experience with examples of how to interpret and use the information with concrete actions. The difficulty is being sure that the actions proposed do not have a negative effect on any of the other priorities for the process: product quality and product losses. The more priorities that are being juggled, the harder it is to make decisions that benefit them all, however at the current time, energy isn't on the list of priorities to be juggled so being the lowest on the list would still be an improvement.

#### **5.6 Scale of the potential impact**

The ultimate aim of this work is to enable operators to control and intervene in the pasteurisation process in a way that minimises energy consumption.

The Carbon Trust Accelerator report for Dairies (The Carbon Trust n.d.) identifies influencing factors on the energy used in pasteurisation as:

- key set point temperatures e.g. input, pasteurisation temperature and output temperature
- efficiency of the regeneration section
- non-useful running (plant is in pasteurisation mode, but the output is limited/compromised i.e. by low feed volumes)
- design and commissioning factors such as plate area and number of heat exchange stages

The Carbon Trust Industrial Accelerator Guide (The Carbon Trust n.d.) addresses the area of impact of inefficient running of dairy processing equipment; in particular pasteurisation. The guide highlights data from 3 sites studied where time spent in excess water circulation (i.e. greater than 10 minutes duration) was responsible for increasing the specific pasteurisation CO<sub>2</sub> by between 16 and 18%. Further data within the report shows how the specific pasteurisation CO<sub>2</sub> is also heavily influenced by the regeneration efficiency. The report gives an example of two sites, one with a regenerator efficiency of 93% and specific CO<sub>2</sub> of 2.5kgCO<sub>2</sub>/m<sup>3</sup> and one with regenerator efficiency of 88% and specific CO<sub>2</sub> of 3.55kgCO<sub>2</sub>/m<sup>3</sup>. Spotting reduced efficiency of regeneration can lead to significant CO<sub>2</sub> and financial savings. Again the Carbon Trust guide contains relevant quantification, pointing out that an increase of 1% in regeneration efficiency can lead to an average saving of 0.2kgCO<sub>2</sub>/m<sup>3</sup> and for a site processing 350,000m<sup>3</sup> p.a. this would be approximately £10,100 annual saving for every 1%.

Clearly identifying and quickly remedying falling regeneration efficiency can lead to energy savings, as can identifying times when the pasteurisation unit is not operating as it should. Examples from our experience include: plant left in water recirculation mode for longer than necessary; attempting to pasteurise at low or erratic flow rates; water recirculation at too high a temperature (i.e. greater than pasteurisation temperature). With the monitoring data currently available, these issues can be very hard to detect from routine hourly checks where key temperatures are recorded.

This work focused on dairy pasteurisation as an example of a “black box” with regard to energy consumption, but the application is not limited to dairy pasteurisation. As pointed out in the Carbon Trust Industrial Accelerator Guide (The Carbon Trust n.d.); pasteurisation is common to all dairy processing sites and so opportunities for savings could potentially be replicated across the industry. Pasteurisation is used in numerous food and drink processes and in addition there are many other process elements that could be described as a “black box” in that the energy consumption is notable, control interventions are necessary, however limited data on energy consumption is available. Examples include Clean In Place (CIP) operations, spray dryers and evaporators. The operator role will be similar across the dairy and wider food and drink industry and therefore the potential to apply the findings. Further research would be worthwhile to investigate the possible similarities in operator role across other food and drink industries.

## 5.7 Summary

To summarise the main observations:

Communication on energy use is happening at site B, and noticed by operators (this is not the case at all sites). Operators said that energy was talked about in daily meetings.

Information (e.g. via SCADA) relating to the energy use of the plant, is not provided to operators. There is very limited information that the operators can easily use to interpret the efficiency of plant in order to make interventions.

In general, the operators didn't consider energy use of the plant as something they could control or influence. They are unable to edit routines, but have considerable autonomy in how they schedule and manage when those routines run. The scheduling and management choices have an impact on energy consumption of the process.

Operators demonstrated very good understanding of factors affecting energy use (pointing out capital fixes such as moving the sugar input closer to mixing tanks and ways to interpret the operation of the plant that would indicate inefficient operation e.g. filter clogging and increasing pressures). At site B, operators knew that they should try and reduce water recirculation time and incorporated that into their planning. Operators at site A took active steps to

reduce water consumption (such as careful scheduling of washing operations), as it was a priority that had been communicated to them.

A number of the operators felt that with better information on the efficiency of the plant, that there were bound to be actions they could take during running of the plant. No specific actions were identified.

The job that the operators do involves balancing multiple priorities and uses a great degree of skill. A variety of control priorities were mentioned as things that the operators take into account when planning how they are going to achieve their required volume targets: cost in general, product loss, water minimisation, chemical use minimisation, time, and understanding of pinch points along with the quality and health & safety requirements they must meet.

The operators learn how to do this complex scheduling task through experience and communication with one another.

Site A used the Aspen™ trending software which was highly praised by all interviewed as a good way to visualise plant operations. The trend view shows how the parameters are changing; are temperatures and pressures increasing or decreasing? Is the process stable? The trends give a greater context for interpretation than a single spot reading.

At site B operators had mixed feelings about the SCADA screens (some negative, some neutral), there was no consistent view on what was the best presented information.

## 6. Conclusion

We observed that operators have an important potential role to play in controlling processes for energy efficiency. The operators are at the frontline, and are able to allow for energy reduction in scheduling decisions and in dealing with unexpected issues. They also have detailed knowledge of the process and are well placed to spot potential energy improvements and beneficial energy related projects. However, on the sites studied, which are part of an organisation declaring a progressive policy towards reducing energy, the operators cannot utilise fully their potential to save energy as they are not typically considering and looking for the issues listed in 5.2 and 5.6 such as low regeneration efficiency or cold utility running in water recirculation mode. Aggravating factors include a lack of communication regarding the importance of energy reduction, insufficient monitoring of data, and lack of appropriate visualisation of the available data. As set out in section 4.1 and 5.1 operators were observed to be capable of interpreting data, making decisions and problem solving to account for numerous site priorities. They were given the autonomy to intervene in the process. Therefore if given the data relating to energy consumption the operators do appear to have the necessary skills and autonomy to utilise that data to reduce energy consumption of the process. As demonstrated by the Carbon Trust (Carbon Trust n.d.) the gap between best and worst performance in liquid milk processing is a factor of 10. And as set out in section 5.6, there are significant cost savings possible from action such as improving regenerator efficiency and reducing unnecessary water recirculation time.

It is important to present energy consumption data to operators, and to communicate to them the need to save energy. From the viewpoint of operators, pasteurisation plants can appear as a black box, in that some inputs and outputs are known, but the energy consumption proper is hidden from view. However, even when the energy consumption information is presented (such as in the case of the evaporators) the attempt to control energy is not always made. This is due to lack of emphasis on the need to save energy from management and site culture, rather than to any innate difficulty that the operators might experience in doing so. The conclusion that communication and information provision are important to motivate process energy reduction behaviours back up well established energy management principles (Smith, 2013). These observed difficulties in controlling pasteurisation for energy efficiency might well extend to other types of plant.

The use of ethnography and semi-structured interview reveals that the operators have the skills to manage a variety of priorities and build them into their choices regarding how they schedule the running of the plant and when they intervene. The operators use building blocks of standard routines and are well versed in adapting the schedule in order to control for other priorities such as time saving, water reduction or product loss.

As discussed in the literature review (section 2.3), Verhulst and Boks (Verhulst & Boks 2014) study human factors relating to the implementation of sustainable design practices and find issues to be; resistance to change, internal

communications, empowerment and organisational culture. If we assume the issues affecting change in this environment may be similar it could also be hoped that the level of empowerment or autonomy that the operators experience is a positive factor, as is the existing organisational culture. We find that the change in practice would be minor given that the operators are already used to factoring site priorities into control decisions. All that remains is effective internal communication.

The starting point of this study was to understand the human factors in pasteurisation process control for energy and understand “why is controlling for energy efficiency within pasteurisation so difficult?”. Our starting hypothesis was that contributing factors were:

- Lack of data on energy consumption
- Poor visualisation of energy data
- Low level of autonomy of the operator
- Conflicting control priorities
- Energy not communicated as a priority

We find that lack of autonomy and conflicting control priorities are not problematic but that lack of data, poor visualisation and communication do contribute to processes like pasteurisation (high energy demand and significant complexity in operation) not being controlled for energy reduction. That these issues are present on sites from a company that considers itself to have a progressive energy policy points to a further issue of lack of holistic or systems approach to tackling energy consumption on this type of process and site.

It is recommended that to facilitate energy reduction operators should be given:

- Communication regarding the importance of reducing energy
- Information in real time regarding the efficiency of the plant, ideally using a trended view showing changes over time. Also beneficial would be the chance to discuss and share what opportunities they identified.
- Information regarding the type of standard actions they could implement and look out for, e.g. similar to the advice to minimise water recirculation time. The identification of typical actions and interventions that can improve efficiency should be the subject of further work in this area.

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## Data Statement

All underlying data to support the conclusions are provided within this paper.

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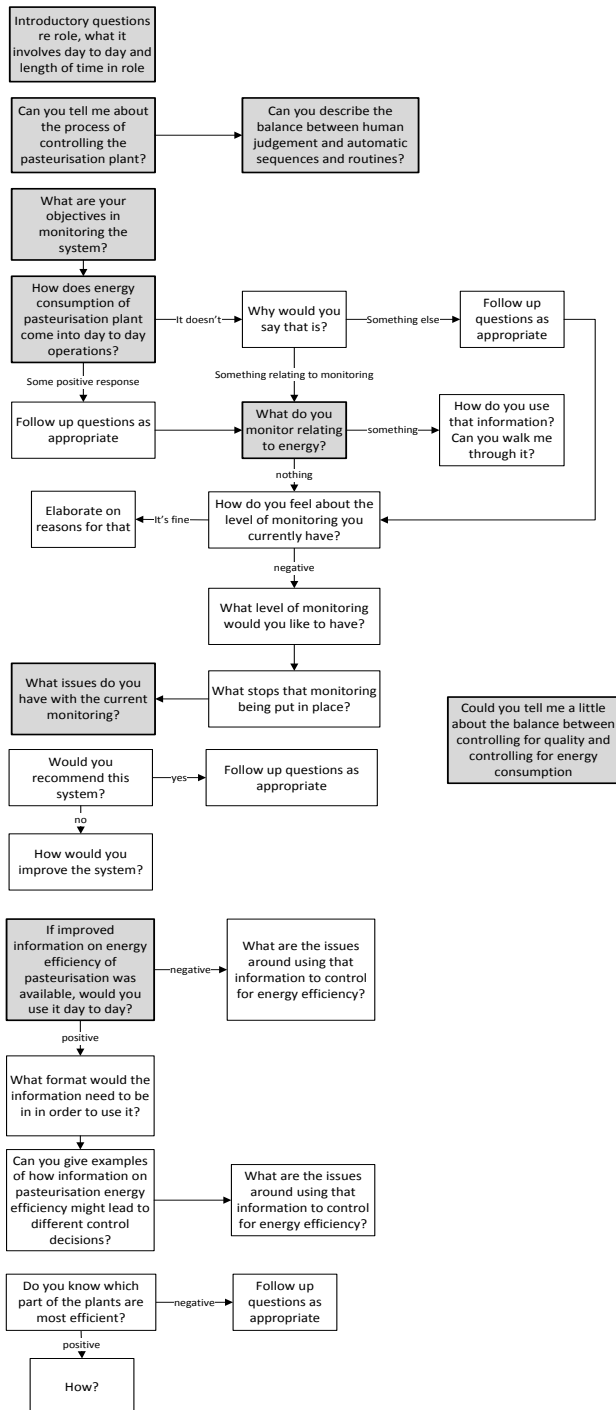
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## Appendix A – Interview Question Flowchart

The interview plan, constructed before interviews, is listed below. Note that (1) some questions did not result in productive answers and are not discussed in this paper (2) the methodology was flexible so that questions posed in-situ could divert from the plan (3) for clarity of presentation, the responses on Tables 1 to 4 have been restructured, and do not necessarily map onto the original plan.



## Appendix B Comments on Plant Control

Publication of a complete plant instrumentation diagram is prevented by space limitations and commercial confidentiality. Reference [1] lists the operations taking place and in the professional experience of two authors (CC, AT). (1) The feedstock can take many forms: raw milk; recovered cream; skimmed milk, changing from day to day according to supply and demand. Many storage tanks are available for feedstock (2) There are many processes depending on desired product: pasteurisation (milk and cream); separation plus pasteurisation (cream); evaporation and spray drying (powdered milk) (3) There are many product storage tanks, potentially connected to the many processes. Each storage tank is to hold a temperature suited to the product concerned.

By means of example, Figure 3 indicates the automatic control of a pasteuriser. Three-term (or PID) controllers will hold certain temperatures and flow rates to set point for fixed periods of time (indicated as SP (set point) on Figure 3). Automatic control does not deal with certain issues that therefore demand the attention of the operator, these include; feedstock variability (e.g. cream percentage and incoming temperature), sequencing of clean in place, the deployment of produce/ feedstock to/ from storage tanks, ... (Note that in the deployment of storage tanks to plant the operator needs to deal with many-to-many relationships, and integrate deployment into shift and transport patterns such that product is not wasted.)

[1] <http://www.fao.org/wairdocs/lead/x6114e/x6114e06.htm>

## Appendix C

### Control Room Case Study – Day in the Life of a Pasteurisation Unit

#### Observations on the role of process control operators

*This case study is assembled from the ethnographic observations made during the site visits.*

It's 8:30am and the control room is packed with men in white overalls and boots and blue hairnets and beard covers. Each takes his turn to update the rest on what the priorities of his shift are, it is matter of fact. A stern word about product wastage from packing errors is followed by smiles with news of an initiative to reduce product lost to drain during line change overs. Product loss is the big issue. Meeting over, most of the masked men break into smaller groups, discuss a last few points and then head out into plant and production rooms.

The control room is quiet and just a few people remain, three men sit at a long control desk with three stations each having three screens. The atmosphere is calm; they are busy but not stressed. Each one has a part of the plant to monitor: liquid process, evaporators, dryers. The new shift are checking what is already underway, moving silently from window to window on their screens. They each record key numbers in paper logbooks in front of them. Once they are fully tuned into what is going on "out there", they start to relax, the radio is switched on and the first words exchanged are about who wrote the song. Everything else is in hand.

The cream pasteurisers are part of the liquid process desk. Liquid process is the hardest desk to master. Operators start on the dryer desk, learn how to control that part of the process then move to the evaporators maybe for 6 months before they are ready to work on liquid process. The SCADA systems do much of the work, following programmed routines. The difficulty comes from the number of different elements and routines that must be understood, planned in, watched, and controlled. An operator on liquid process is interacting with the milk intake (selecting tanks and authorising unloading of new milk supplies), storage of raw milk (tank volumes, cleaning routines, temperatures), separators to send the skimmed milk off to the evaporator (and from there the dryer) desks. The cream from the separators then goes to storage (again tank volumes, cleaning routines, temperatures) and on to pasteurisers. Cream may also be returning from other parts of the process waiting for pasteurisation. The routes into and out of the liquid process sphere of influence can appear as a spaghetti junction. Some human decisions are by the book; test the cream for acidity level, phosphate, and dissolved solids, check the age and temperature. *Does it pass? Yes? Ok send it on.* But many of the judgements are about planning how to most efficiently achieve the required product volumes. The operators are able to use their judgement to manage and balance the elements of the plant:

- Delaying the start of a process to allow greater through flow.
- Stopping a process early to avoid too small amount held in the next tank.
- Waiting to clean so that the process can be started without an additional pre-heating routine.

The liquid process section has the most process elements to keep a vigilant eye on.

The operators intervene in and direct the process in a number of ways:

- Scheduling. This is done typically at the start of each shift, deciding how best to achieve the required volumes of product.
- Reactive changes to the schedule. With regular frequency during the day, operators will need to respond to changes and issues, interact with other departments and change the scheduled or plan as necessary to keep operation as close to optimum as possible.
- Breakdowns and faults. A variety of issues can arise; failure of equipment, leaks, fouling, flow disruptions. Every shift will have some issue to deal with though the severity will vary. Technicians can be called on to deal with issues, and

the operator must interact and control the process appropriately, simpler problems can be resolved through operator intervention within the SCADA system, such as restarting or editing a process (tank changes, flow changes).

-Selection of recipes. As described above, the operator has to select from and customise (to a degree) the various SCADA recipes available. The frequency of this action will vary depending on the run time of the process. For pasteurisation running for 16hrs, it may only be once per shift.

-Recording and reporting. Frequencies are set at each site, typically on an hourly basis – key readings such as pasteurisation temperatures and pressures must be recorded.

Not all of these interventions will have an impact on energy efficiency, the recording and reporting element will have minimal impact other than that for some sites it may be the only time that operators are looking at key metrics such as temperature. Selection of recipes will also have minimal impact as this is an area where the operators have less autonomy and it is in scheduling that the bigger impacts are made.

Spotting of breakdowns and faults can have an important impact on energy; the sooner that problems are detected – the less time that the plant may be running in an inefficient mode e.g. fouled heat exchangers, incorrect temperatures, running when product may not be usable.

The biggest impact comes from the scheduling choices and the reactive changes to schedule for example to avoid standby running (e.g. on hot water circulation mode), minimising CIP operations, choosing the most efficient plant.

On a typical day, the cream pasteurisation units could be processing raw cream, pasteurised cream bought in from other sites, recovered butter or recovered spreads. Today cream pasteuriser 2 is running, continuing what will be a near to 16-hr-long run from the previous shift. The pasteurisation process is in hand, there is very little to see. The control process keeps the pasteurisation temperature at such a steady level, flat for hours on end. Even flow disruptions are quickly dealt with as the SCADA system corrects the steam input to the hot plate heat exchanger. The operators are watching the process, but their focus is on other areas of liquid process. *Are the separators running steadily? What time should we schedule the line change over? Did you see that level drop?* The interaction between the controllers is jovial and a clarification or question about interaction of their section slips easily between light-hearted discussion.

A line change-over is taking place; more people have arrived to watch. The team are trialling a new line change over routine, the balance between automatic and manual input has shifted much more to the manual but most of the people here are just interested in how it works and how much product will be saved. The process steps are counted through and the process caught at the right moment, the line changeover process responsibility moves across to the next desk smoothly. One of the watchers will shortly be editing the routines so that the product saving will be automatic *“it will all go to where it needs to go”*. It's a success, 1300 litres saved, and again the groups discussing the outcome quickly dissolve away back to day to day business.

This day has been another quiet one for the cream pasteurisers, but has it been energy efficient? Who knows? The operators would not, the key pasteurisation temperatures are recorded as a HACCP<sup>5</sup> requirement but the temperature traces are not viewed on the trend system but even if they were, the system would fight to keep them level and flat against any issues. As much steam as necessary would be used, as much chilled water as is needed. No monitors are present on the steam and chilled water here, apart from valve % and these are not trended or reviewed by the operators, so their activity for the day is unknown. Has the regeneration unit done its job and reused as much of the waste heat as possible? Who knows? The regeneration temperature trend on cream pasteuriser 2 is not looked at *“what is the point of it?”* is the view. The operators know their stuff, a fouled heat exchanger can be spotted by problems with back pressure or if the feed pump % is ramping up. There are a lot of tags to be reviewed, especially on liquid process, and the regeneration temperature is not a priority. The trend system helps the operator to get a better

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<sup>5</sup> Hazard Analysis and Critical Control Points. HACCP procedures require food business operators to have a comprehensive plan related to ensuring food safety, in particular “Establish and implement effective monitoring procedures at critical control points”. Pasteurisation temperature being a key control point.(Dairy UK, 2010)

overview of the plant, instead of looking at a single (possibly fluctuating) tag value, the trends for tags are plotted in custom formats so that the critical levels, temperatures, %s, densities etc. for a process can be seen over time. A deviation from the norm becomes obvious and the operators can anticipate required action long before it becomes an alarm issue. The separator is viewed on the trend system to make keep an eye out for failures. But the pasteurisation process runs steadily on, showing a calm face on the SCADA screen with none of its hidden detail visible. In the flesh, the pasteurisation units are just as enigmatic - a tangle of clean, plain, shiny, silver pipes - descending into and rising out of the plate heat exchanger silently without mark or label.

Energy monitoring data is available on the evaporators. Tag values for kWh electrical consumption and kg/hr steam use, displayed on small tag boxes on the main screens. The operators, who know these plants inside and out, are almost unaware of them and feel that they represent elements of the plant that they are unable to control *"We have to use that energy, the energy that the evaporator uses I haven't really got any control over, I can't slow it down, I can't reduce the temperature of it, it is what it is, so I can concentrate on getting what we got coming out of the other end right"*. As far as they are concerned, these numbers are intrinsic to the running of the equipment, and cannot be influenced. Anyway, it's not a priority, they have many things they need to look out for and can handle multiple priorities, but this isn't even on the list. Numerous parameters relate to quality of the final product, dependent on where it is in the process. Losses have to be avoided, that is a clear message. Product losses are profit losses. Up to recently their water supply was limited so scheduling of all operations had to be done with availability of water in mind. Reverse osmosis and water recovery technologies slot in with all other critical plant. The supply is now improved, but the mind-set has been happily fixed – *"the amount of water we use is important"* – it has a cost and an impact on the process. Energy has a cost, but it isn't limited, the cost isn't being counted here. *"I've never really been taught to monitor the energy side of it, I'm not sure if anyone else does neither...if we had the correct kit to monitor it, I think it would be quite easy"* *"Someone probably looks at energy"*, but that person is unknown down in the control room.

The pasteurisation process has finished, it is no longer on autopilot, but is being brought down by an operator, making selections and checking all is well. He is choosing the correct CIP routine and will let that run, checking in occasionally. Other issues are more pressing, there is a lot to look at on liquid process and pasteurisation today has presented a calm and steady face. To know what went on behind the scenes would require data downloads and additional calculations. The day was a quiet success as far as all the major indicators would say.